CCLRC
Rutherford Appleton Laboratory

ISIS

Beam Loss Control on the ISIS Synchrotron

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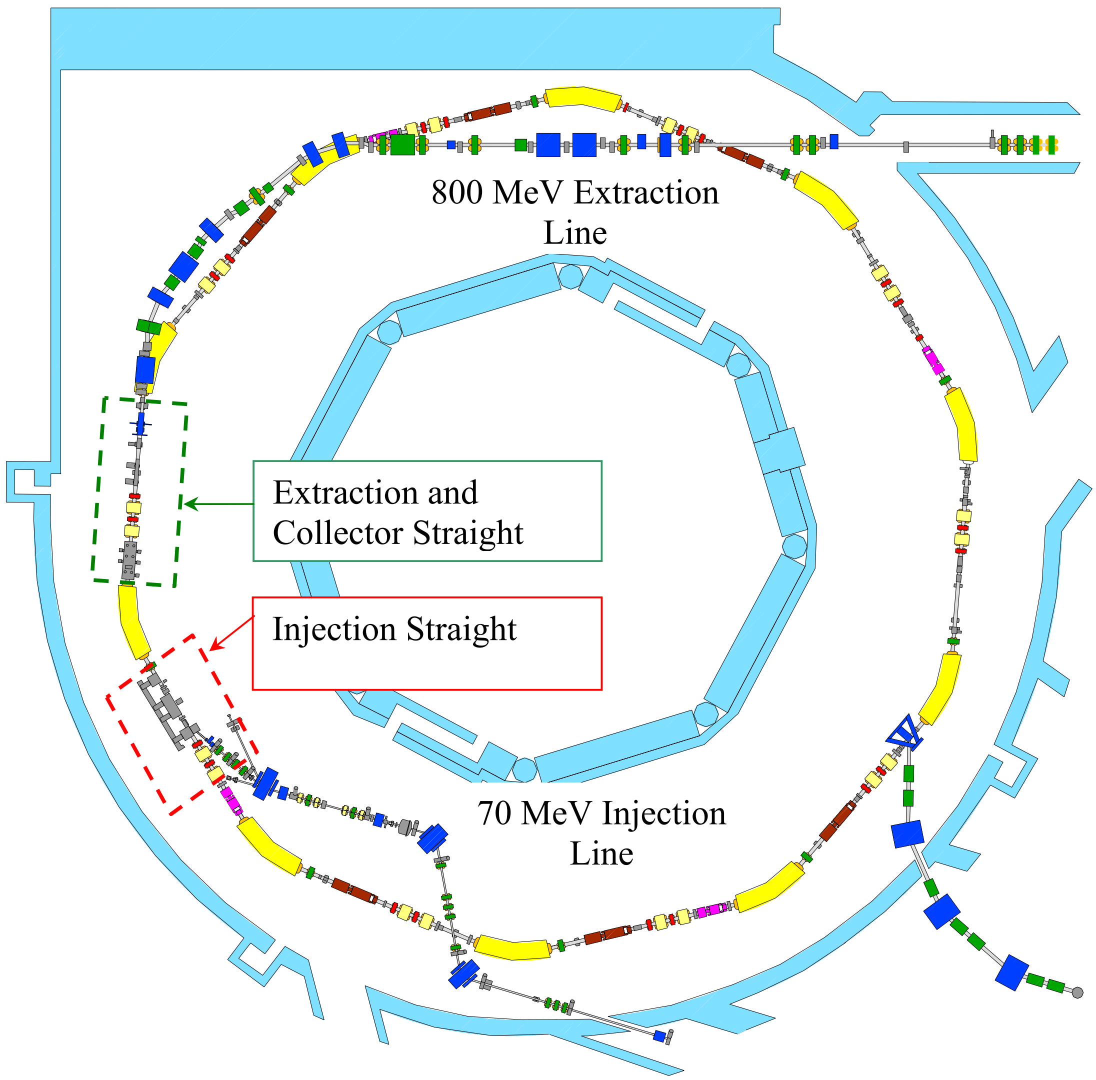
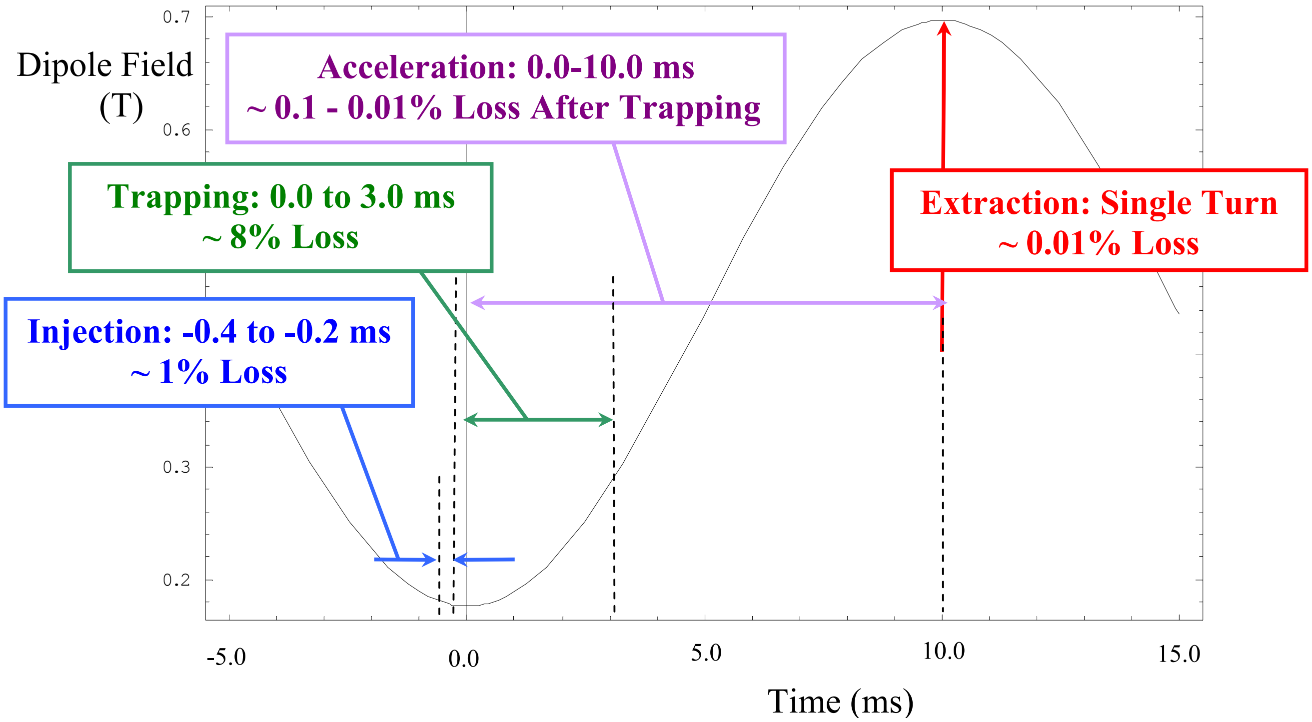
- The ISIS Synchrotron and Beam Losses
- Motivation and Aims
- Outline of Collectors
- Measurements
- Simulations
- Plans
- Conclusions

The ISIS Synchrotron



ISIS Ring Operation

Relation to 50 Hz Main Magnet Field



- Injection

  Accumulate 2.8×10^{13} Particles over 130 turns

  Anti-correlated horizontal and vertical painting
- Trapping

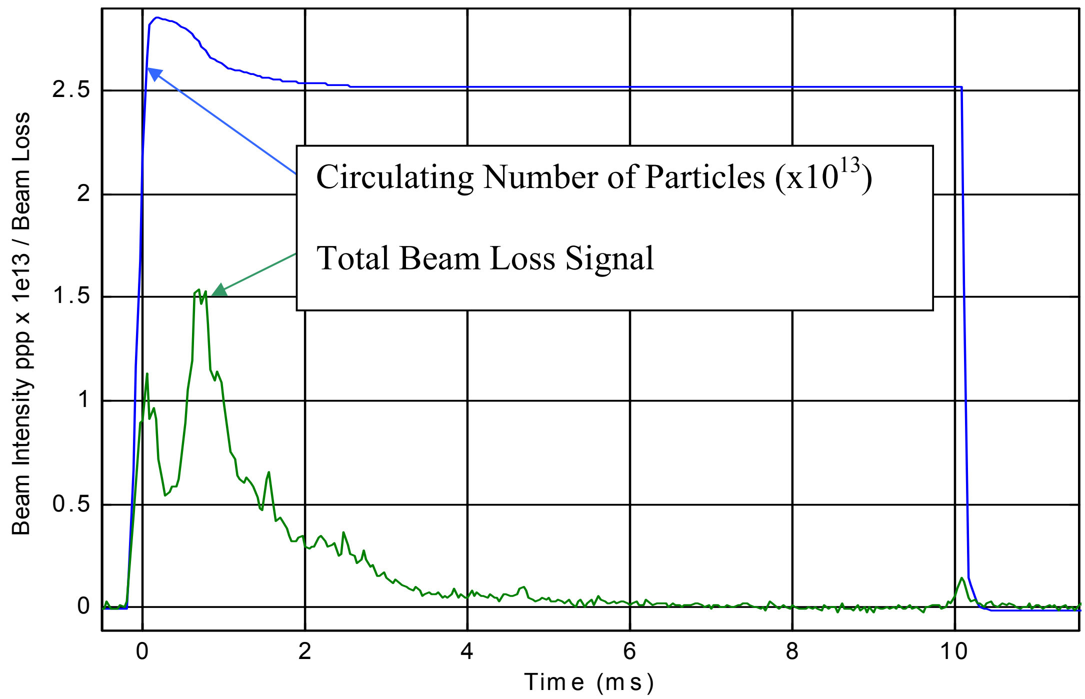
  Rapid Bunching in ~ 1 ms under space charge

  Most Losses ≤ 100 MeV
- Acceleration

  Rapid 70-800 MeV Ramp in 10 ms: RF 140 kV/turn
- Extraction

  Single turn, Fast kicker (rise time 200 ns)

ISIS Ring Losses



ISIS Synchrotron Parameters

	Present Operation	Upgrade
Energy Range	70 - 800 MeV	
Intensity	2.5×10^{13} ppp	3.8×10^{13} ppp
Rep Rate	50 Hz	
Mean power	160 kW	240 kW
Mean Current	200 μA	300 μA
Injection	130 turn, charge-exchange paint injected beam of ~ 25 π mm mr	
Acceptances	horizontal: 540 π mm mr with dp/p ± 0.6% vertical: 430 π mm mr	
RF System f_{RF} *sweep* V_{RF} *peak*	Single Harmonic h=2 1.3-3.1 MHz 140 kV/turn	Dual Harmonic and h=4 2.6-6.2 MHz 80 kV/turn
Extraction	single turn, vertical	
Nominal tunes	Q_h=4.31, Q_v=3.83 *adjusted with trim quads*	

- 240 kW Upgrade - *being installed*
- ISIS Second Target Station - *approved*
- ISIS 1-5 MW Upgrades - *under study*

Motivation and Aims of Work

- Motivation

  Loss Control Crucial for Operation

  Minimise doses, damage, downtime

  Problems with Dipole RF Shield Damage

  Problems with Inconsistent Loss Control

  Must be reliable after 300 μA Upgrade

  Higher power (160 kW to 240 kW)
  Loss at higher energy ? Enhanced Halo ?

- Aims

  Maximal Localisation of Loss in Collector Straight

  Achieve Consistency ~ Understand Variations

  Understand Key Factors Affecting Performance

  Collector Design Features
  Beam Loss Characteristics

Outline of Collectors – Basic System

- System Situated in Shielded Straight Section

  - Momentum and Horizontal Betatron System
    Primary jaw near dispersion max
    Downstream collimators to protect components

  $\Rightarrow$ For dominant trapping loss - single turn removal

  - Vertical Betatron System
    Primary/Pre-deflector
    Secondary jaws

  $\Rightarrow$ For betatron loss - multiple turn removal

- Key Features

  Intended for loss $\leq$100 MeV, total power of ~2 kW
  Active Handling Features: Modular, Quick Removal

  Combined Graphite/Copper Construction
  Higher A material on surface - enhanced removal
  Lower A material in volume - lower activation

  Horizontal
  Transverse Angle to Enhance Impact Depth

  Vertical
  Pre-Deflector For Small Impact Depths

Outline of Collectors – Recent Enhancements

- Obsolescence Program – Opportunity to Upgrade

  Relative importance of some features uncertain
  Cautious approach – keep all key features

- Longer Graphite Jaws to Operate at Higher Energy

  Increase length from 50 to 300 mm

- Additional Secondary Horizontal Betatron Jaws

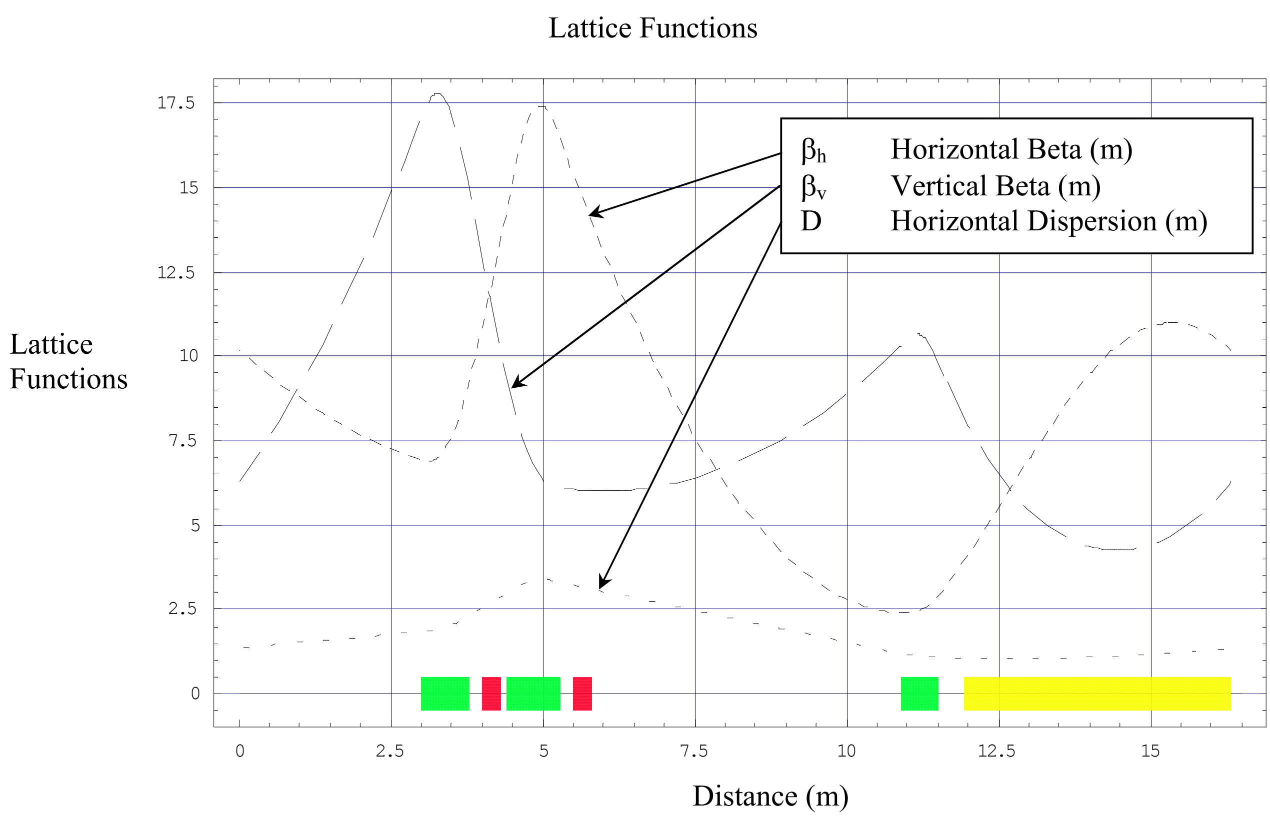
- Additional Vertical Jaw for Extraction Halo Scraping

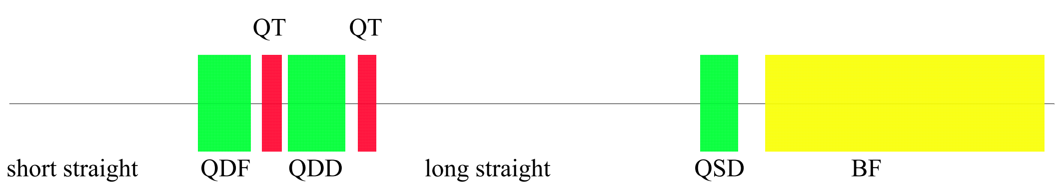
- Further Additional 'Experimental' Jaws

  For Enhanced Protection
  For Studies ~ Experiments/Diagnostics

- Deposited Power Measurements in Jaws

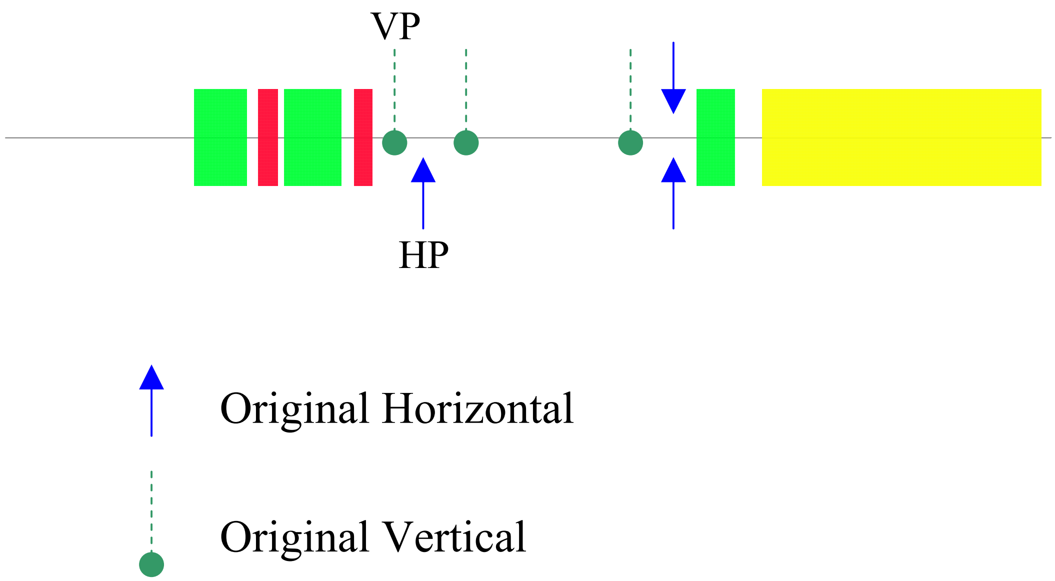
  Flow rate and temperature change in cooling water


Lattice Functions
17.5
15
12.5
10
7.5
5
2.5
0
0
2.5
5
7.5
10
12.5
15
Lattice Functions
Distance (m)
β_h Horizontal Beta (m)
β_v Vertical Beta (m)
D Horizontal Dispersion (m)


QT
QT
short straight
QDF
QDD
long straight
QSD
BF

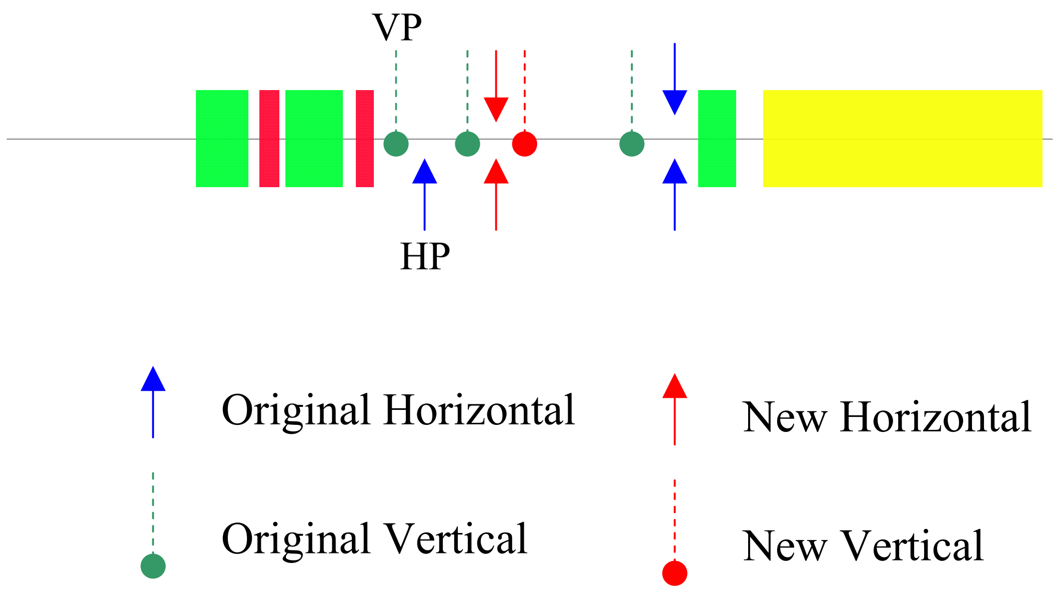
Basic Layout of Collimators on ISIS

Schematic View From Above



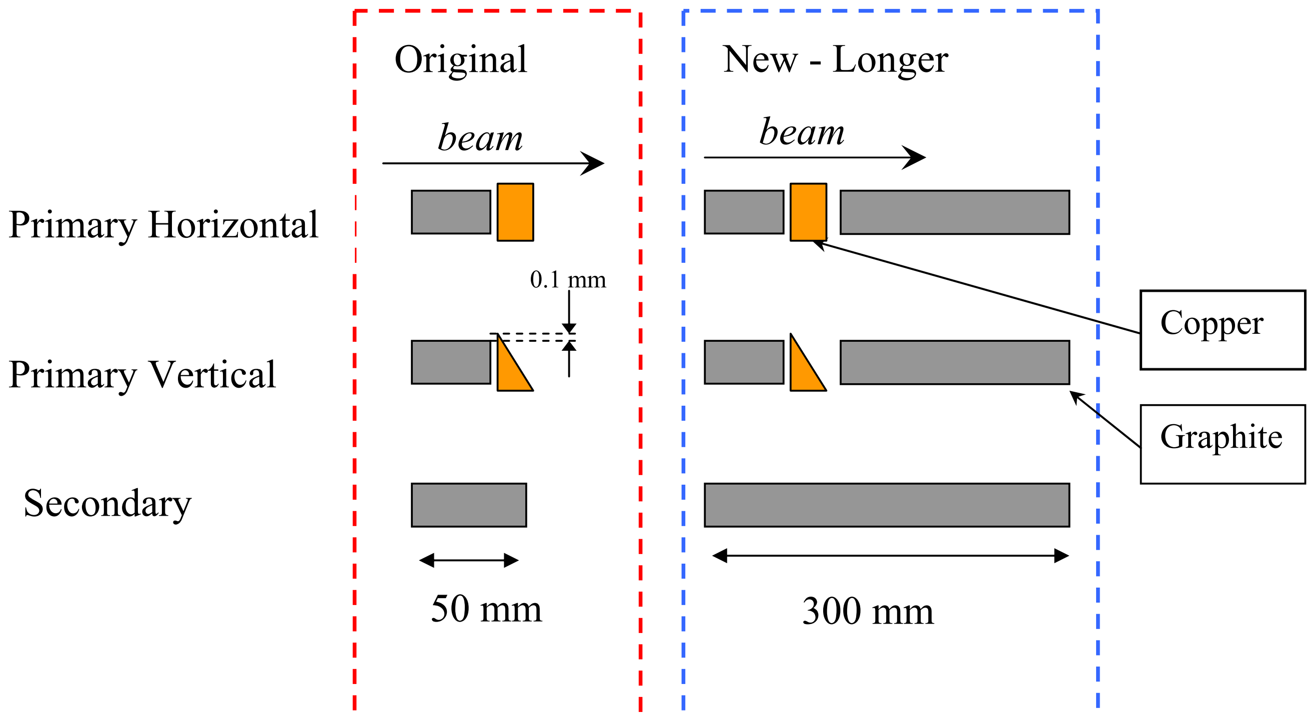
Layout of Collimators on ISIS - Including new Jaws

Schematic View From Above

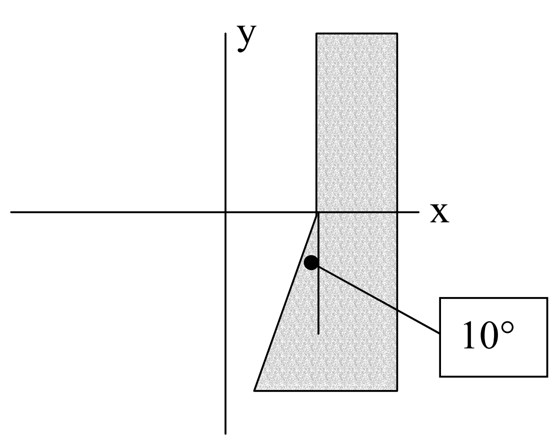


Geometry of Collectors

- Longitudinal - Graphite and Copper



- Transverse - Angle On Horizontal Jaw



Beam Loss Measurement

- Developing More Detailed Analysis of Beam Loss

  - Properly defined loss distributions
  - Suitable for comparison with simulations

- Need Spatial Loss Dis^{n} as function of time/energy

⇒ Beam Loss Monitors ~ estimate of spatial distribution

40 around entire inner circumference
Sensitivity varies by 10^2 over 70-800 MeV

⇒ Toroids ~ calibrated loss with time

⇒ Heat Deposition on Jaws ~ total loss in each plane

- Analyse Losses in 0.5 ms Bins through 10 ms Cycle

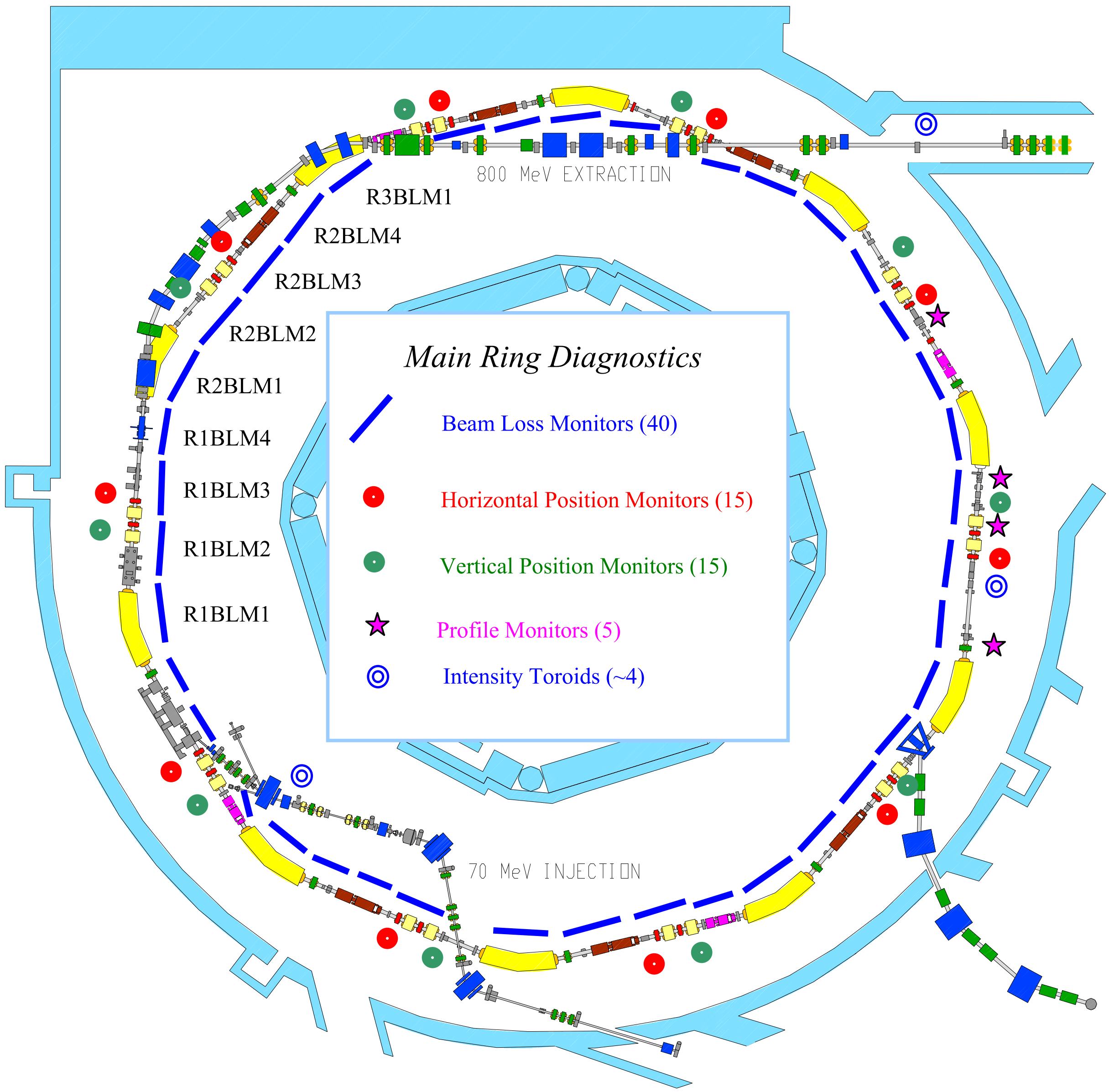
  BLM Signals
  ~ integrate BLM signal over 0.5 ms interval/bin
  ~ minimal beam energy/BLM gain variation over bin

  - *Relative Spatial Loss Distribution in each 0.5 ms bin*

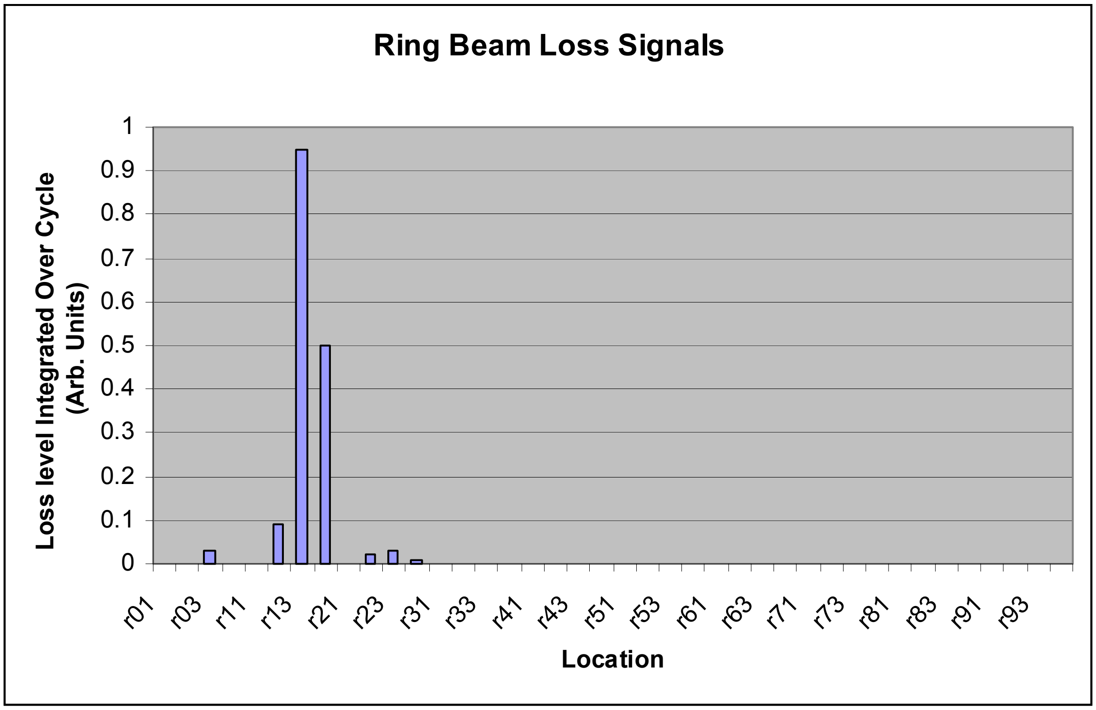
  Toroid Signals

  - *Total Lost Power in each 0.5 ms bin*

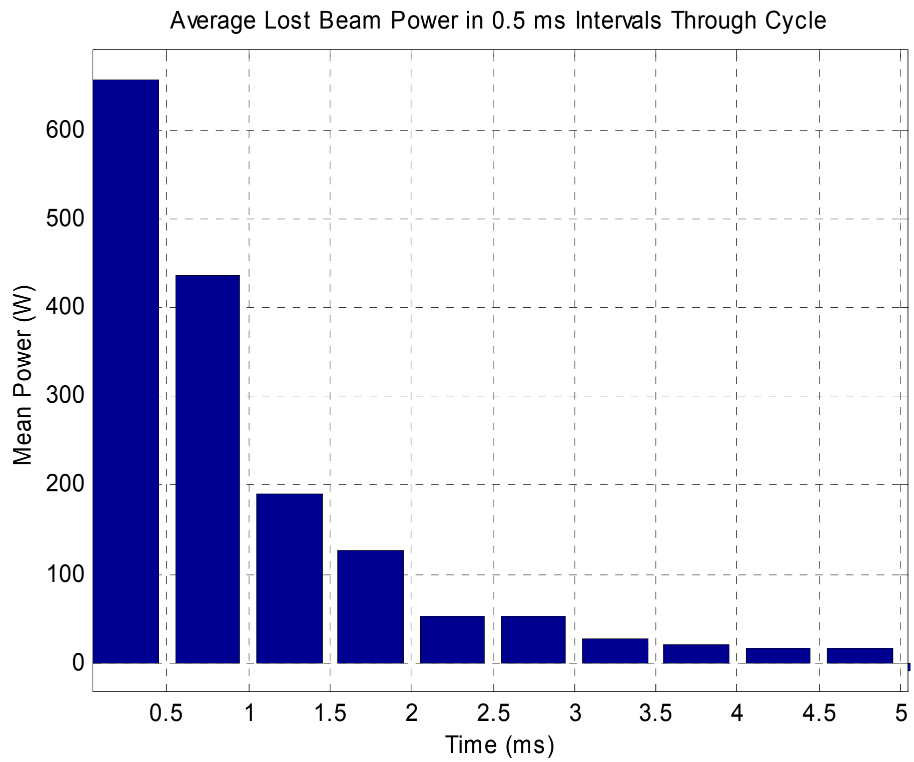
Schematic Layout of Ring Diagnostics

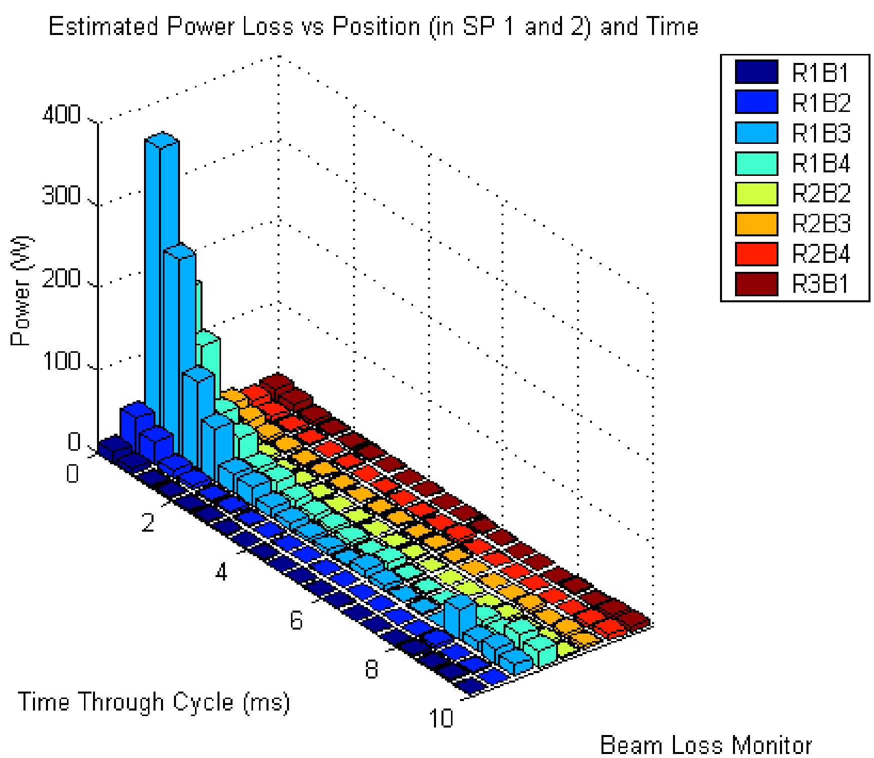


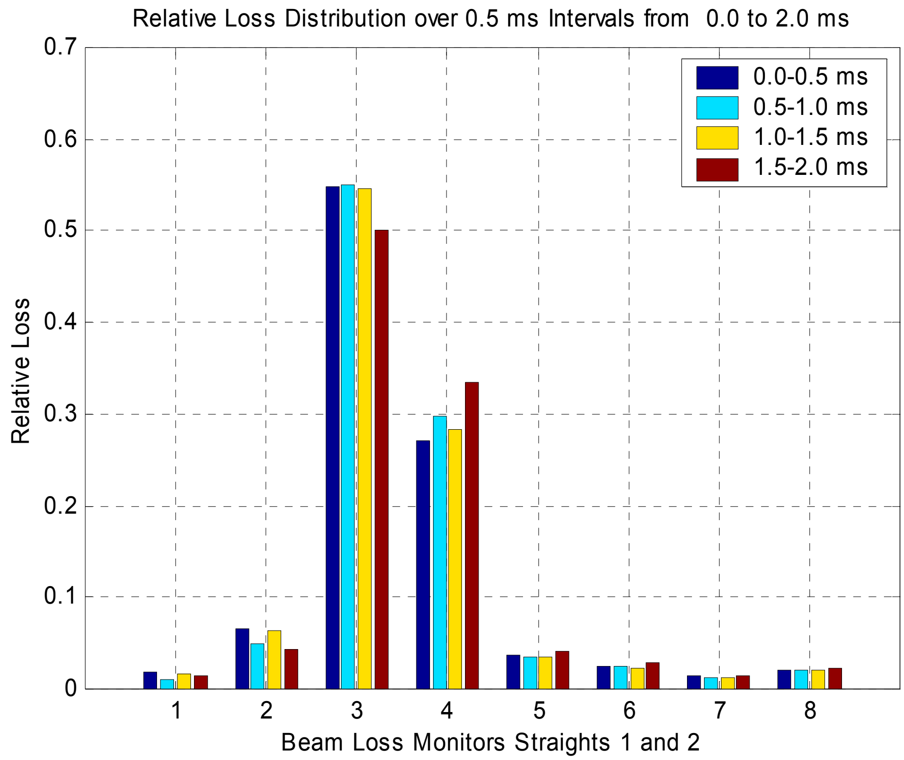
Distribution of Total Loss

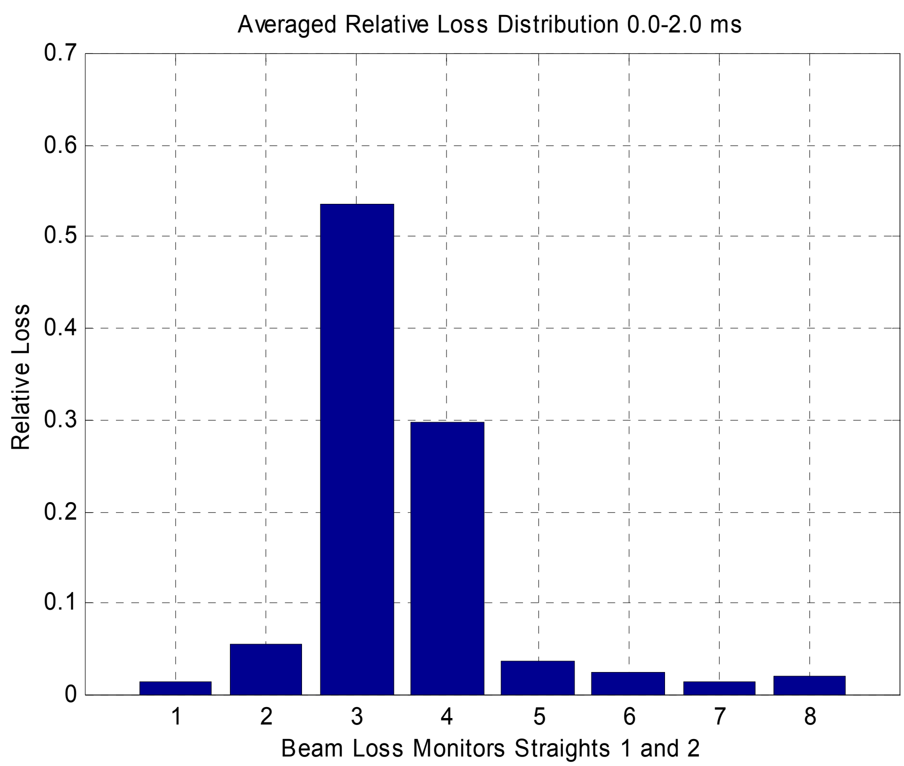


- During Normal Operation, Most Loss is Confined to ~2 of the 10 machine superperiods


Average Lost Beam Power in 0.5 ms Intervals Through Cycle
Mean Power (W)
600
500
400
300
200
100
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (ms)


Estimated Power Loss vs Position (in SP 1 and 2) and Time
Power (W)
400
300
200
100
0
0
2
4
6
8
10
Time Through Cycle (ms)
Beam Loss Monitor
R1B1
R1B2
R1B3
R1B4
R2B2
R2B3
R2B4
R3B1


Relative Loss Distribution over 0.5 ms Intervals from 0.0 to 2.0 ms
0.0-0.5 ms
0.5-1.0 ms
1.0-1.5 ms
1.5-2.0 ms
Relative Loss
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1
2
3
4
5
6
7
8
Beam Loss Monitors Straights 1 and 2


Averaged Relative Loss Distribution 0.0-2.0 ms
Relative Loss
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1
2
3
4
5
6
7
8
Beam Loss Monitors Straights 1 and 2

Simulations

- Simulation Program - as used for ESS studies

  Monte Carlo Simulation of Proton/Jaw Interaction
  - energy loss, straggling, multiple scattering
  - inelastic and elastic nuclear interactions
  - 3-D model of jaws

  Detailed Model of Lattice and Apertures

- Approach

  Study Proton Loss Distribution ~ not Activation
  Model Collimation Process ~ not Loss Mechanism
  Characterise Loss by: Plane and Growth Rate

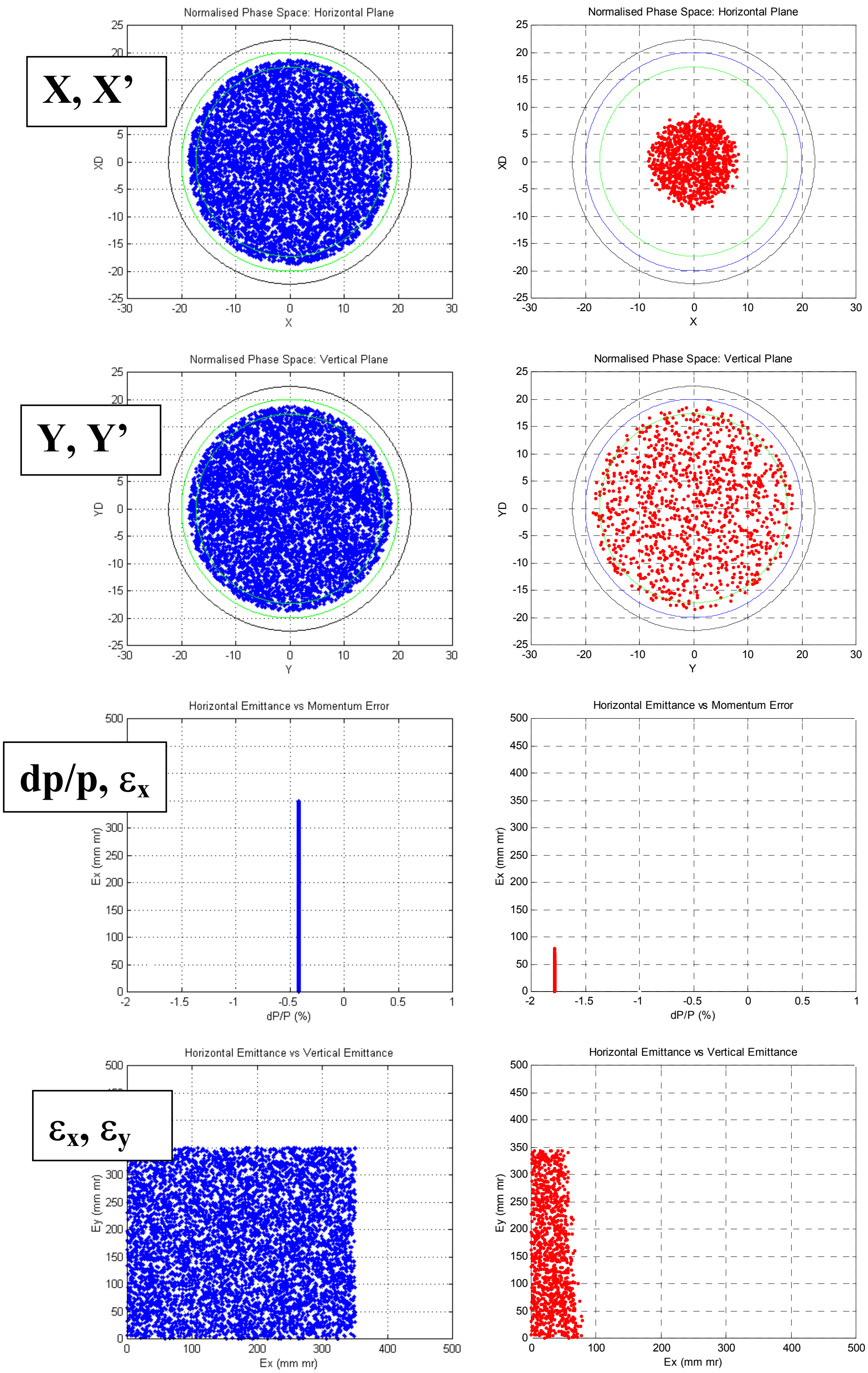
- First Simulations for ISIS

  Concentrate on main losses at ~ 100 MeV
  No machine errors included yet

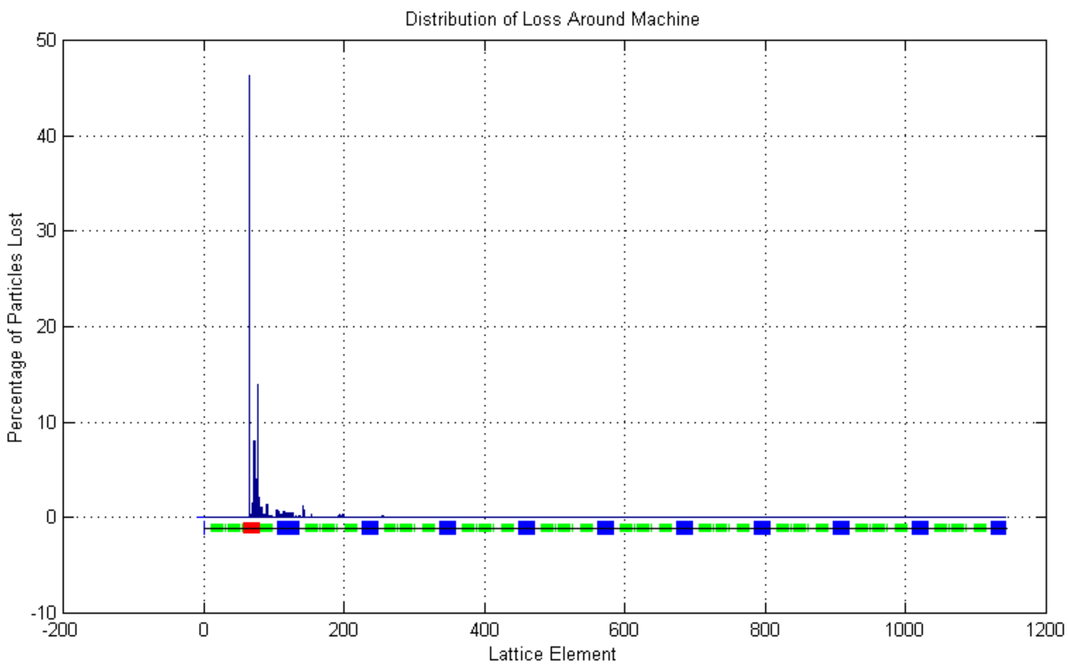
- Simulations for Growth Rates of 10 & 100 μm/turn

  - Vertical Loss
  - Horizontal Loss
  - Longitudinal Loss

Momentum Loss ~ 10 µm/turn



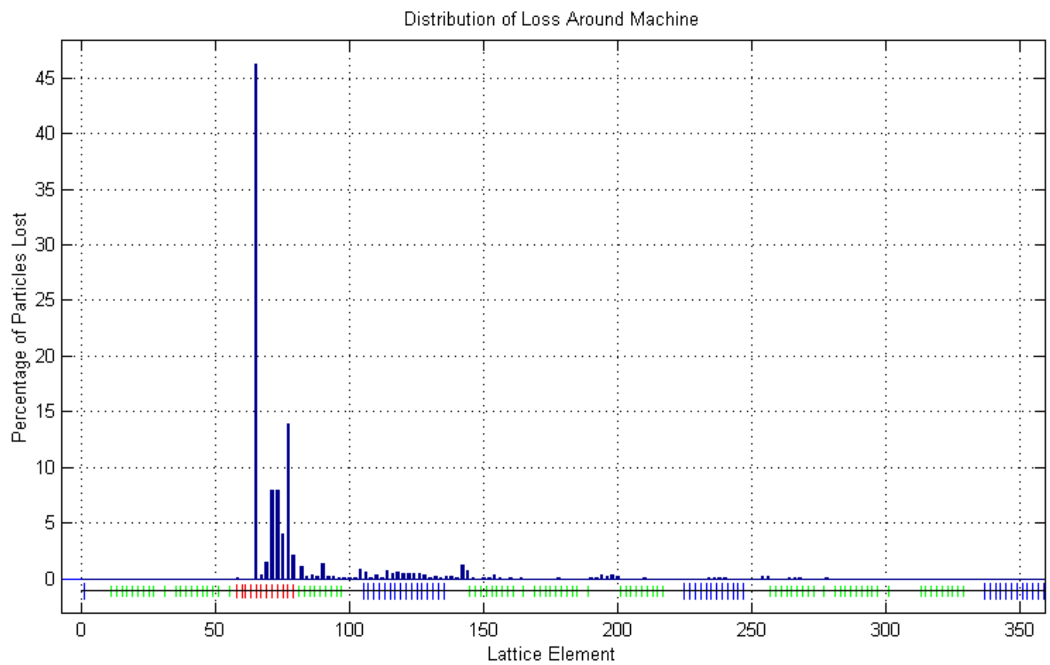
Momentum Loss ~ 10 μm/turn

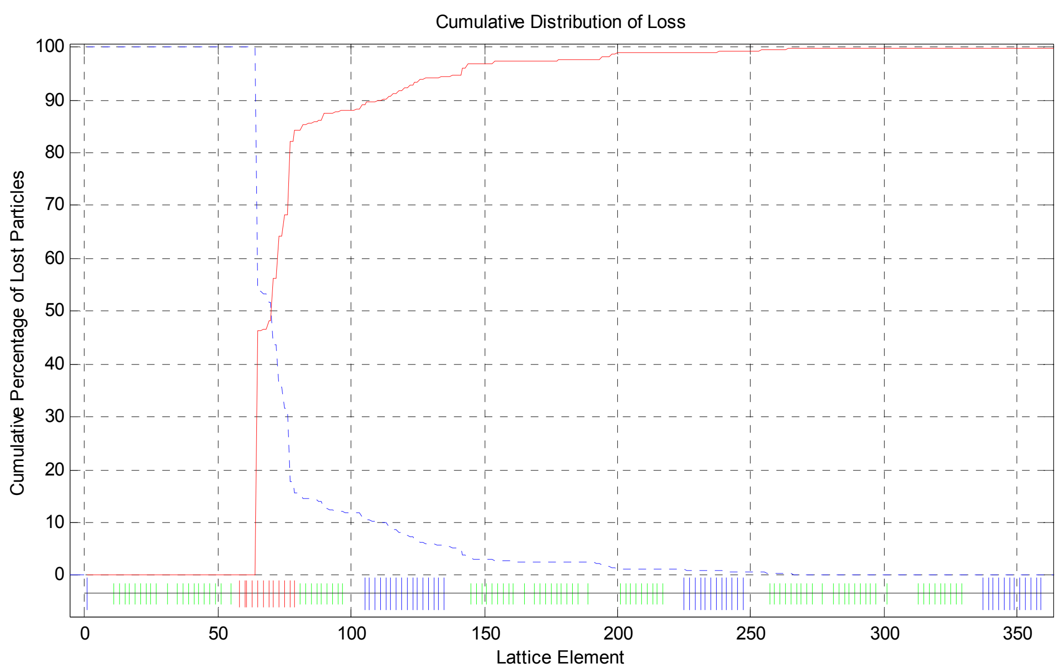


- Shows Loss around all 10 superperiods

  Red - Collimators
  Blue - lattice dipoles
  Green - lattice quadrupoles

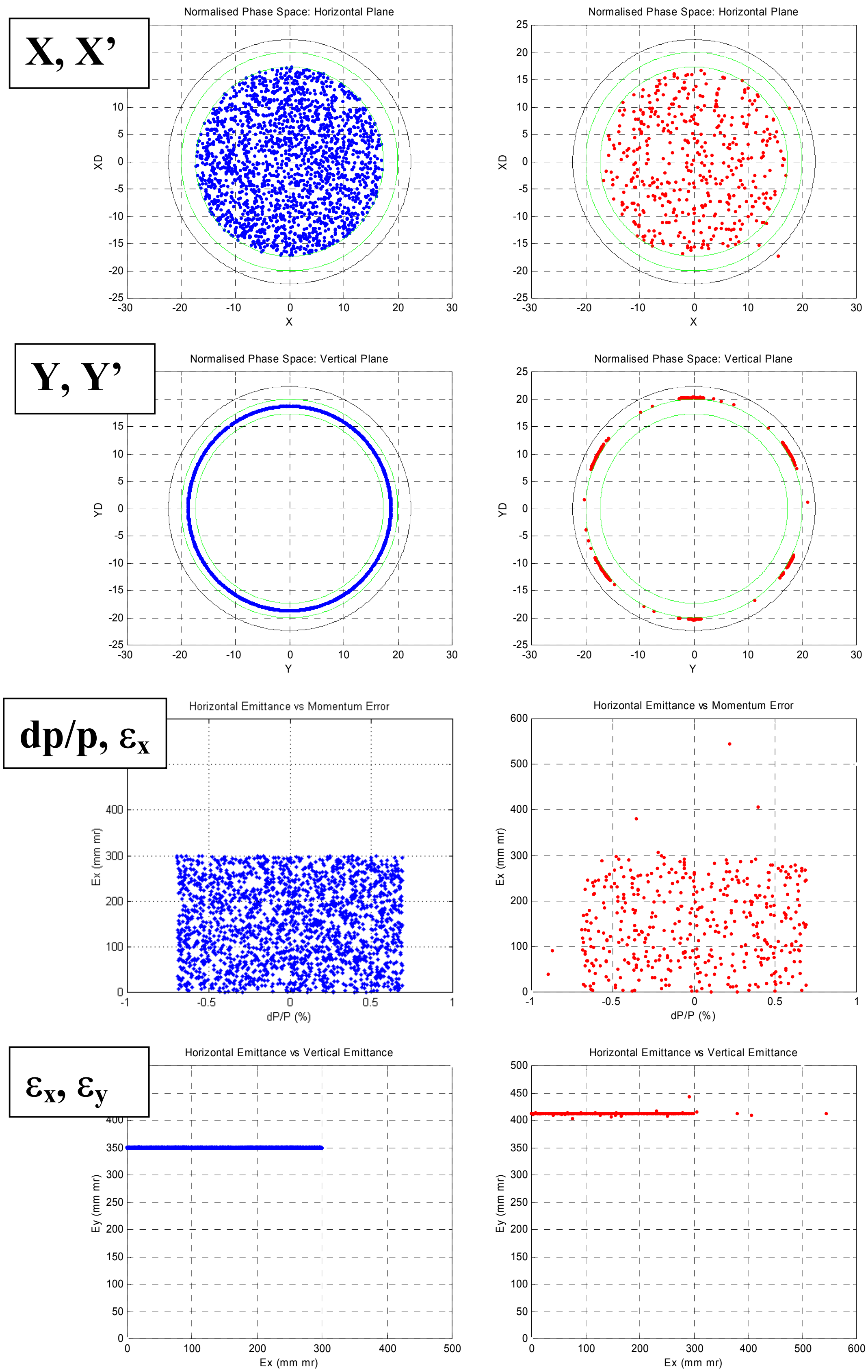
Momentum Loss ~ 10 μm/turn



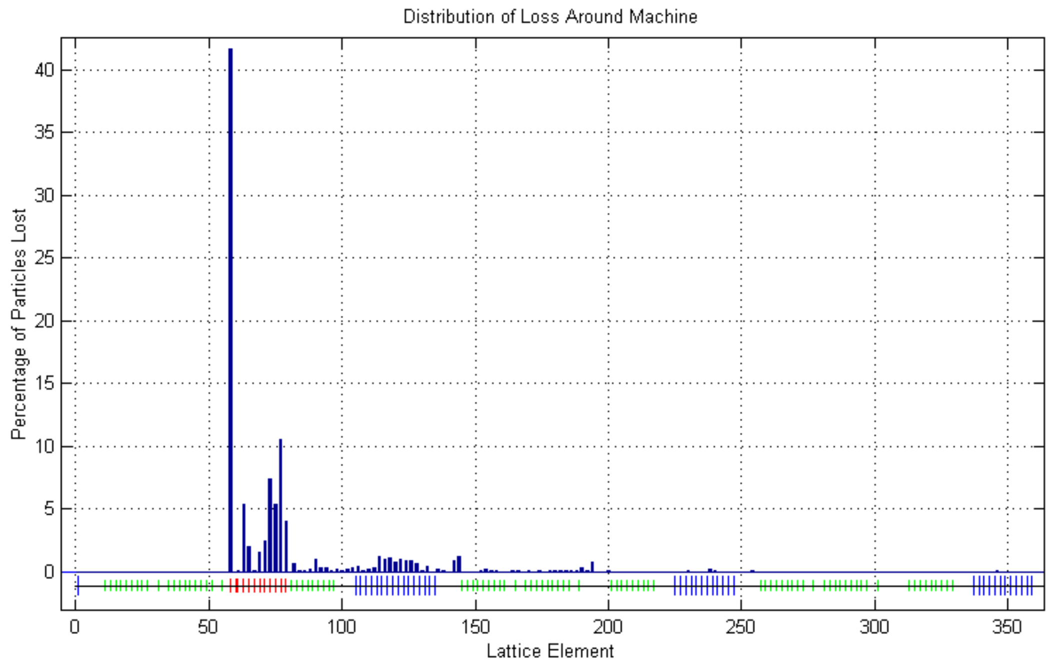


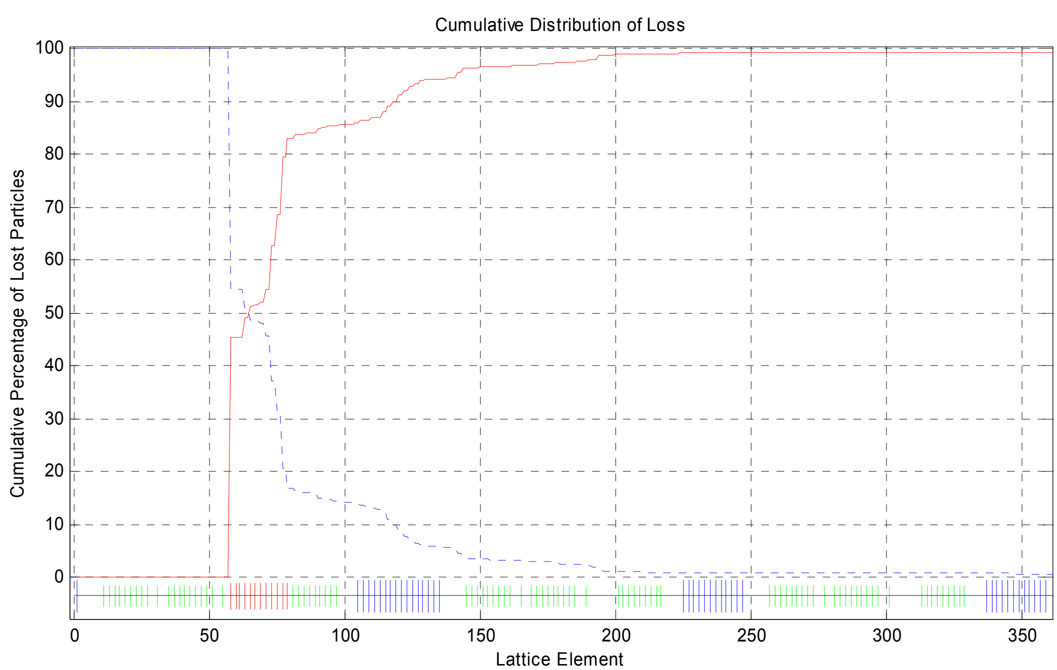
- Shows Loss distributions in superperiods 1, 2 & 3

Vertical Loss 10 μm/turn



Vertical Loss 10 µm/turn





Comparison of Simulations with Measurements

- Loss Measured During Normal Operations

  So beam loss is the sum over all components:
  momentum, horizontal, vertical

- Power Deposition on Jaws Suggests

Horizontal/Trapping Loss	~ 600 W	ie 75%
Vertical	~ 200 W	ie 25%

- Compare Measurements with Simulation

  Simulated Particle Loss Summed over Each BLM
  Compare with Vertical, Horizontal, Momentum Loss

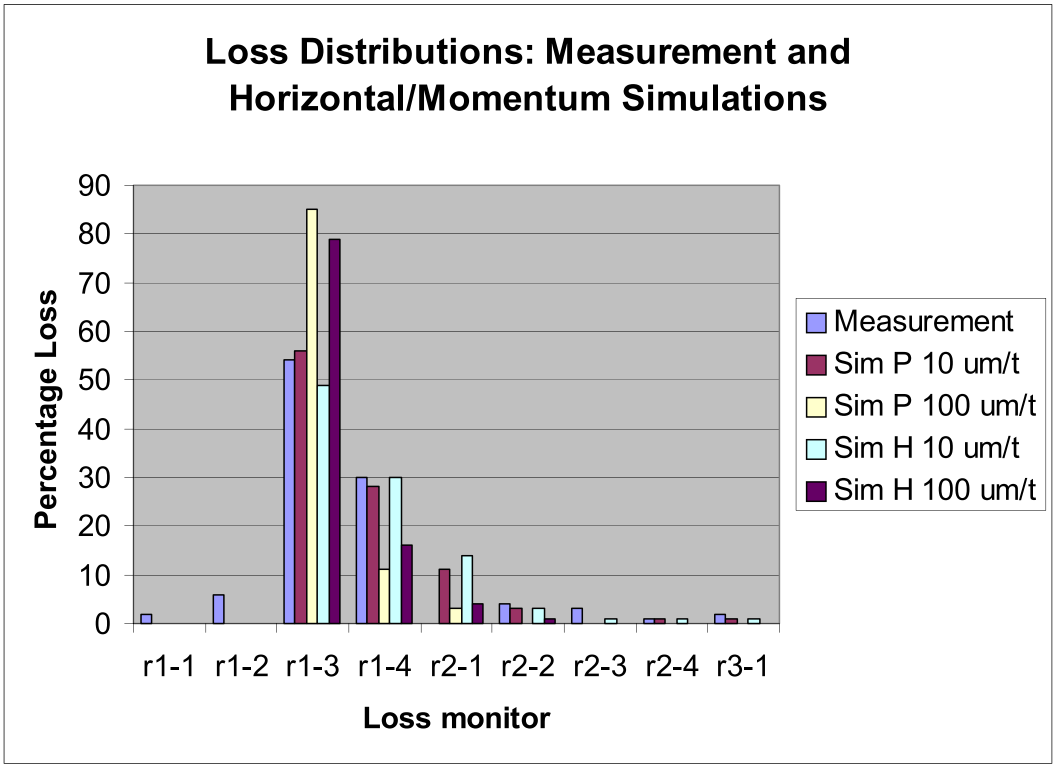
~ Reasonable Agreement - for selected Growth Rate!

- Limitations in BLM Measurements

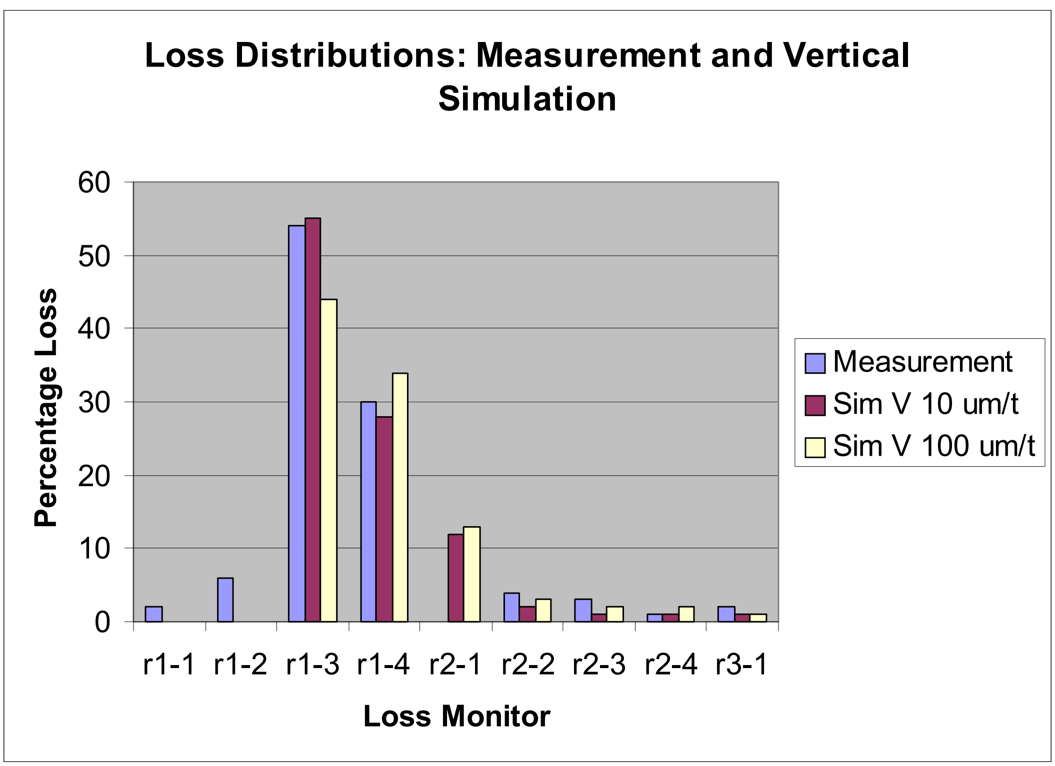
  Dependence on local geometry and materials
  Overlapping response
  ~ could easily be ±5% error

- Limitations in Simulation

  Machine errors not included
  High Intensity/Non linear effects not included



Loss Distributions: Measurement and Horizontal/Momentum Simulations
Percentage Loss
0
10
20
30
40
50
60
70
80
90
r1-1
r1-2
r1-3
r1-4
r2-1
r2-2
r2-3
r2-4
r3-1
Loss monitor
Measurement
Sim P 10 um/t
Sim P 100 um/t
Sim H 10 um/t
Sim H 100 um/t



Loss Distributions: Measurement and Vertical Simulation
Percentage Loss
0
10
20
30
40
50
60
r1-1
r1-2
r1-3
r1-4
r2-1
r2-2
r2-3
r2-4
r3-1
Loss Monitor
Measurement
Sim V 10 um/t
Sim V 100 um/t

Results Summary

Percentage of Beam Lost in Region of Each BLM

Loss Type	Beam Loss Monitor									
plane-GR (μm/t)	1-1	1-2	1-3	1-4	2-1	2-2	2-3	2-4	3-1	rest of ring
p -100	0	0	85	11	3	0	0	0	0	0
p -10	0	0	56	28	11	3	0	1	1	1
p -10 a+	0	0	58	28	9	2	1	0	1	1
h -100	0	0	78	17	4	1	0	0	0	1
h -10	0	0	49	30	14	3	1	1	1	1
v -100	0	0	44	34	13	3	2	2	1	1
v - 10	0	0	52	29	13	2	1	0	1	1
v - 10 t	0	0	78	13	5	2	1	1	0	1
Measurement	2	6	54	30	-	4	3	1	2	0

Statistical Uncertainty in Simulations ±1%
Uncertainty in Measurements ~ ±5% (under study)

a+ - with transverse angle increased from 10-20°
t - with tantalum primary

Plans

- Work above is a first attempt to compare simulation and measurements on ISIS ~ still many details to study

- Look in more detail at BLM Limitations

- Study each System and each Type of Loss

  Momentum & Horizontal Loss
  Vertical Loss

- Dependency of Loss Control on Loss Mechanisms

  Longitudinal Trapping ~ Growth Rate
  Transverse Space Charge etc. ~ Growth Rate

- Develop Measurements

  Improve Heat Deposition Measurement (Halo?)
  Other monitoring: scintillators, thermocouples, IR …

- Bench Marking Measurements

  Set up well defined loss and measure distributions

- Feed Into Refinement of Collimator Set up and Design

- Ready by 2006-2007

Summary

- Loss Control Systems on ISIS Ring Work

  But could be better – important for 0.240 MW

- Reasonable Agreement with Simulation

  Much detail still to be understood

- Studies Continue …

- Acknowledgements

Contribution from many members of the ISIS Accelerator Division gratefully acknowledged.